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1. Your reference 483GB 25AUG00 E563660-1 D02651  
P01/7700 0.00-0020929.6

2. Patent s 0020929.6 25 AUG 2000  
(The Date)

3. Full name, address and postcode of the or of each applicant (underline all surnames) Renishaw plc  
New Mills  
Wotton-under-Edge  
Gloucestershire, GL12 8JR

Patents ADP number (if you know it) 2691002  
If the applicant is a corporate body, give the country/state of its incorporation United Kingdom

4. Title of the invention Optical Measuring Apparatus For  
Measuring Tools On Machines

5. Name of your agent (if you have one) J Waite, J T Jackson, et al  
"Address for service" in the United Kingdom Renishaw plc, Patent Department  
to which all correspondence should be sent New Mills  
(including the postcode) Wotton-under-Edge  
Gloucestershire, GL12 8JR  
United Kingdom

Patents ADP number (if you know it) 7796139001

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earlier patent applications, give the country (if you know it) (day / month / year)  
and the date of filing of the or of each of these  
earlier applications and (if you know it) the or  
each application number

7. If this application is divided or otherwise Number of earlier application Date of filing  
derived from an earlier UK application, (day / month / year)  
give the number and the filing date of  
the earlier application

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:  
a) any applicant named in part 3 is not an inventor, or  
b) there is an inventor who is not named as an applicant, or  
c) any named applicant is a corporate body.  
See note (d)) Yes

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| Abstract          | 0  |
| Drawing(s)        | 3  |

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11. I/We request the grant of a patent on the basis of this application.

Signature

Date 25.08.00

AGENT FOR THE APPLICANT

12. Name and daytime telephone number of person to contact in the United Kingdom

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OPTICAL MEASURING APPARATUS FOR MEASURING TOOLS ON  
MACHINES

The present invention relates to an optical measuring  
5 apparatus which enables a coordinate positioning  
machine (such as a machine tool) to determine the  
position of an object relative to a reference point.  
It may, for example, be employed on a machine tool for  
toolsetting operations.

10

A known tool setting device for use on a machine tool  
includes a light source which generates a fine beam of  
light which is incident upon a detector. During a  
toolsetting operation, the machine is operated to move  
15 the tool in a direction transverse to the direction of  
propagation of the light beam until a part of the tool  
interrupts passage of the light beam. Detection of  
this interruption is used to produce a trigger signal  
in the detecting unit, which is used by the machine to  
20 establish the relative position of its moving parts in  
~~order to determine dimensions of the tool. Such~~  
devices are known, for example, from German Patent Nos.  
DE 42 385 04 and DE 42 448 69, French Patent No.  
2,343,555, European Patent No. 98,930 and US Patent No.  
25 4,518,257. The devices may be used additionally for  
measuring the length or diameter of a tool to monitor  
tool breakage or wear.

The devices disclosed in the above-mentioned patent  
30 specifications use a narrow light beam into or through  
which the tool is passed. The detection units detect  
when the tool breaks into the beam from the resulting  
drop in the intensity of the light falling on them.  
The trigger signal may be produced as a result of a  
35 predetermined drop in the intensity of light falling on  
the detector as the tool enters the beam.

A problem which arises with such optical measuring apparatus is that coolant used on the machine can drip through the beam, or be thrown off the rotating tool  
5 into the beam, during the measuring operation and give rise to false trigger signals.

One method of overcoming this problem which is currently used, is to program the software in the  
10 machine controller to perform several measurements until a pre-selected number of measurements falling within a given tolerance have been obtained. The position of the tool is then assumed to be the average of these measurements. This method can give rise to an  
15 unacceptable increase in the measurement cycle time if a significant number of repeat measurements have to be taken.

The present invention seeks to alleviate this problem  
20 by providing a method of measurement which can differentiate between a genuine tool detection signal, and a signal produced by a coolant drip.

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According to one aspect of the present invention there  
25 is provided a method of making measurements of a tool on a machine tool using an optical measuring apparatus which includes a light source which generates a beam of light which is incident upon a detector, the method comprising the steps of:

30 generating a signal within the detector each time the beam is interrupted;  
evaluating the frequency and/or duration of the occurrences of said signals;  
emitting an output signal from the detector only  
35 if a signal is also present within the detector in a specified time interval from the generation of a said

signal.

The timing of the signals can be achieved in various ways.

5 In one embodiment of the invention the tool is rotated, preferably, at a known specific speed. This gives rise to the generation of a regular sequence of said signals within the detector as the cutting edge (or edges) of  
10 the tool interrupt the beam. The generation of the first one of the said signals is used to initiate a timing sequence within the detector which sets a time interval ( $t_1$ ) substantially equal to the time taken for one revolution of the tool, followed by a second time  
15 interval ( $t_2$ ) which is substantially shorter than ( $t_1$ ). If it is the tool which has generated the signals in the detector then a second signal will be generated in the time interval ( $t_2$ ) as the cutting edge of the tool comes round again, and if this happens, the detector  
20 emits the output signal.

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Alternatively, the generation of a signal within the detector can be used to start a clock which emits pulses of short duration synchronised with the speed of  
25 rotation of the tool. Again, if a second signal is generated within the detector during such a pulse then the detector emits an output signal. A number of clocks may be used which start sequentially as the detector generates its signals, and each of which stops  
30 if no second signal is generated within the detector during the next one of its pulses.

The invention also includes apparatus for carrying out the method which comprises a light source for  
35 generating a light beam and a detector for receiving said beam and which generates a signal when the beam is

interrupted, wherein the detector includes a detection circuit which generates a signal each time the beam is interrupted, and signal processing means for evaluating the frequency and/or duration of the occurrences of said signals and which emits an output signal only if a second signal is generated by the detection circuit within a specified time interval after the occurrence of said signal.

10 Examples of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig 1 is a perspective view of an optical measuring apparatus incorporating the present invention;

Fig 2 is a representation of the output of the detector of Fig 1; and

Fig 3 is a block diagram representing the basic elements of the apparatus;

20 Fig 4 illustrates in lines 4a to 4f the signals generated in various parts of the signal processing circuit of the detector.

Referring now to Fig 1, the optical measuring apparatus is shown in a set up arranged to operate as a toolsetting apparatus, suitable for use, for example, on a machine tool. The apparatus includes a light emitting unit 10 which emits a beam 12 of light, and a light detecting unit 14, where the light beam 12 is detected. Power and signal control cables to the light emitting and detecting units 10, 14 are routed via inlet ports 16, and both the units 10, 14 are advantageously mounted, via pillars 18, on the base of the machine, either via an intermediate base 20, to which they are both mounted, or directly to the base of the machine upon which they are to be employed.



In operation, the apparatus is used for toolsetting by operating the machine on which the apparatus is mounted to move the tool in a direction transverse to the direction in which the beam 12 is propagating. When a  
5 predetermined level of occlusion of the beam has been established, the detecting unit 14 emits a trigger signal which is used by the machine to determine the relative position of its relatively movable parts, thereby to enable dimensions of the tool to be  
10 determined.

Further mechanical and optical details of an example of such an apparatus are described in our European Patent Application No. 00303749.6 (which is hereby  
15 incorporated into this specification by reference) and are not therefore reproduced here.

Fig 2 shows the output of the detector in various circumstances. The detector output goes high as shown  
20 by a voltage pulse when the beam is occluded to said predetermined extent. As can be seen by the first pulse S1 at the left-hand side of the drawing this can occur when a coolant drip passes through the beam.

25 In the first instance however, the coolant drip is a single occurrence, which produces a single short duration pulse.

When the edge of the rotating cutting tool breaks the  
30 beam there is also a short duration pulse S2, but this is followed by further pulses S3, (only one shown) as the same cutting edge comes into the beam again, or as other cutting edges of a multi-edged tool cut the beam in turn.

35 In order to be able to identify the difference between

occlusion of the beam by a drip, and occlusion of the beam by the edge of the cutting tool for the first time (which is the event which is required to be detected to measure the position of the cutting edge), the invention provides that a timer in the detector sets a first time interval  $t_1$  simultaneously with the detector generating its signal. In a specific embodiment the time interval  $t_1$  is arranged to be equal to the length of time it takes for one revolution of the tool. At the end of the time interval  $t_1$  the timer sets a shorter time interval  $t_2$ .

The detector monitors the time interval  $t_2$  for a second signal which is unlikely to occur if the first signal is a drip. This can be detected by either a high state of the output signal or a rising edge. If the second signal is present the detector issues a "skip" or trigger signal at the end of time interval  $t_2$ .

Since the time intervals  $t_1$  and  $t_2$  are accurately known the instant of the occurrence of the first rising edge of the detector output due to a cutting edge of the tool obscuring the beam can be calculated.

In order to calculate the timings, the speed of rotation of the machine spindle, and hence the cutting tool must be set. In order to keep the time for the measuring operation down a reasonable level, the spindle speed was set during experimentation at 1000rpm so that  $t_1$  was ostensibly 60ms. The interval  $t_2$  however, has to be large enough to cater for slight variations in spindle speed for example up to 5%, which would cause a 3ms variation in  $t_1$ .

To centre the trigger signal in the time interval  $t_2$ ,  $t_2$  is set at  $t_1 + \frac{1}{2}t_1$  which must be equal to 60ms. Thus  $t_1$

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was actually set at 58.5ms.

It is not necessary for the speed of rotation of the tool to be known prior to measurements being taken  
5 since it can be measured by timing the distance between the rising edges of the first two consecutive pulses out of the sequence of pulses generated by the detector. The time interval ( $t_1$ ) can then be set between the second and third rising edges and ( $t_2$ ) can  
10 be timed from the third rising edge.

The basic elements of the apparatus of the invention are shown in block diagram form in Fig 3. The light beam 12 from the transmitter 10 entering the detector  
15 14 impinges on a photodetector in a detection circuit 72 which produces the signals when the beam is interrupted. Signals generated in the detection circuit 72 are passed to a signal processor 74 which includes the necessary timing devices for signal  
20 analysis. The detector output signals are passed directly to the machine controller 80 which stops the machine, and evaluates the machine scale readings to determine the position of the machine.

25 Fig 4 illustrates an alternative embodiment in which one or more clocks in the detector are used, each of which generates a series of pulses initiated by the detector issuing a signal to indicate that the beam has been interrupted;

30 Fig 4a shows an example of a series of events created by a mixture of teeth and drips interrupting the beam;

Fig 4b shows the signals created by these events converted to pulses at the output of a comparator in  
35 the signal processor of the detector;

Fig 4c shows the situation which occurs in the

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detector when a single clock is used;

Fig 4d shows the situation which occurs in the detector when a second clock is used;

5 Figs 4e and 4f respectively show the results of combining the comparator output with the outputs of clock 1 and clock 2.

It can be seen from Fig 4a that the drips occur and interrupt the beam at random intervals while the beam  
10 interruptions caused by the edge of the tool occur at regular intervals. Each beam interruption is labelled as a numbered event E.

Fig 4b shows the comparator output pulses corresponding  
15 to the events.

Fig 4c shows that the first clock starts when event E1 occurs but because there is no event occurring when the second clock pulse is sent to the signal processor the  
20 clock is stopped. The clock is started again on the occurrence of event E3 which is also a drip, but again ~~because its second pulse occurs between events E4 and~~  
E5 it will not see event E4 and will stop. The situation is the same when it starts again at event E5.  
25 Only when it starts again at event E7 will its pulses be synchronised with the occurrences of the cutting edge of the tool interrupting the beam at event E9 and beyond so that a trigger signal will be produced on event E7. This signal will have missed the first  
30 occurrence of the cutting edge interrupting the beam at E6 and will produce an erroneous reading.

With the embodiment which uses two clocks however, as shown in Fig 4d, the second clock will be started on  
35 event E6 because at that time the first clock is running. Since event E6 is an interruption of the beam

by an edge of the cutting tool there will be a further event E7 occurring when the clock pulse is generated. The signal processor will recognise that the clock pulses and the events have now become synchronised and will generate a trigger signal on the rising edge of the pulse. Since the generation of the clock pulses and the beam interruptions are synchronised, the time at which the first beam interruption occurred can easily be determined.

10 The situation is less complex if the first event is caused by a cutting edge of the tool, because the first clock will start and will see a synchronised event during its first pulse and cause a trigger signal at 15 that time.

If a drip occurs between the first and second events this will be ignored by the first clock since it will not occur during its first pulse. Hence the drip will 20 not affect the generation of the trigger signal under these circumstances.

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Although the invention has been described using one or two clocks, other benefits may be achieved if more 25 clocks were used which are set at different frequencies.

For example, the apparatus could be used at different speeds of spindle rotation without having to re-set the 30 timing of the existing clocks, and additional clocks would allow the apparatus to deal with an atmosphere where a lot of drips could be expected. The number of clocks used would be a trade-off between the benefits to be obtained, and the expense of the additional 35 signal processing capability required.

The invention can also be used when the tool is not rotating to measure tool length or diameter during tool setting, or for tool breakage detection. In such an embodiment the tool is moved at right angles to the beam until its tip or flank interrupts the beam. The signal produced by the detector is used to start a clock in the signal processor which evaluates the detector output after a time  $t$ . If the detector output is still high at that time, denoting a signal is still present, the signal processor produces a trigger signal.

In yet another embodiment, the signal processor may incorporate a device which identifies synchronous events. The inputs to the device are samples at regular intervals and the samples are stored in a buffer of fixed length, the new contents constantly overriding the old. The buffer can be implemented using a shift register which monitors the detector output and writes its current state into the shift register each time a sample is taken. If the buffer is ~~split across two bytes, testing for repetitive patterns~~ can be achieved by comparing the two halves. For example, if the sample rate is eight times the speed of rotation of the tool and the result of each sample is shifted through two eight bit registers, when a first signal occurs this shows up as a high (1) in the first cell of the register. The sample moves through the register until it is passed into the first cell on the second half. If there has been no synchronous event the sample passes through the register to the end.

If however, another high sample is received in the first cell of the first half of the register just as the first sample moves into the first cell of the second half of the register then the two halves will

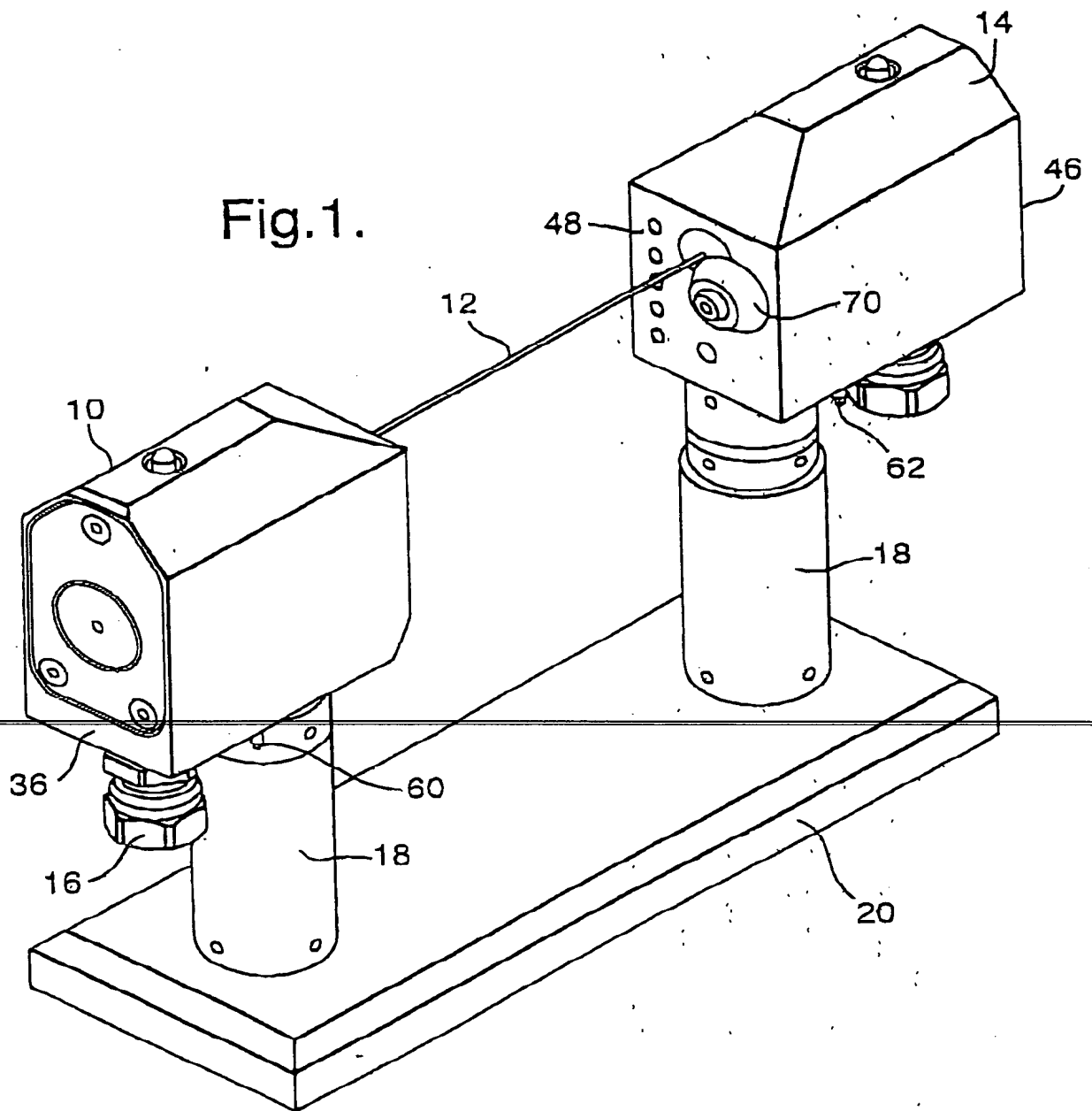
become identical once again and a trigger signal will be issued.

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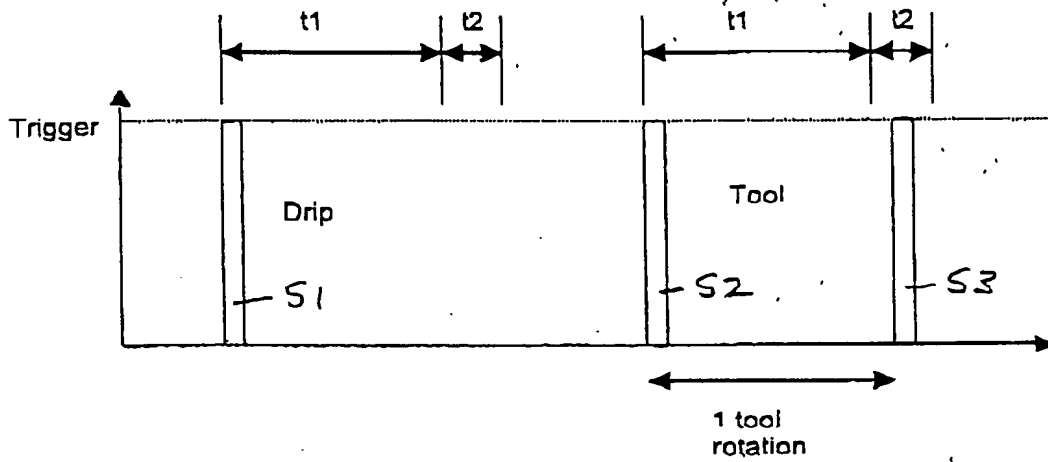


Fig.1.

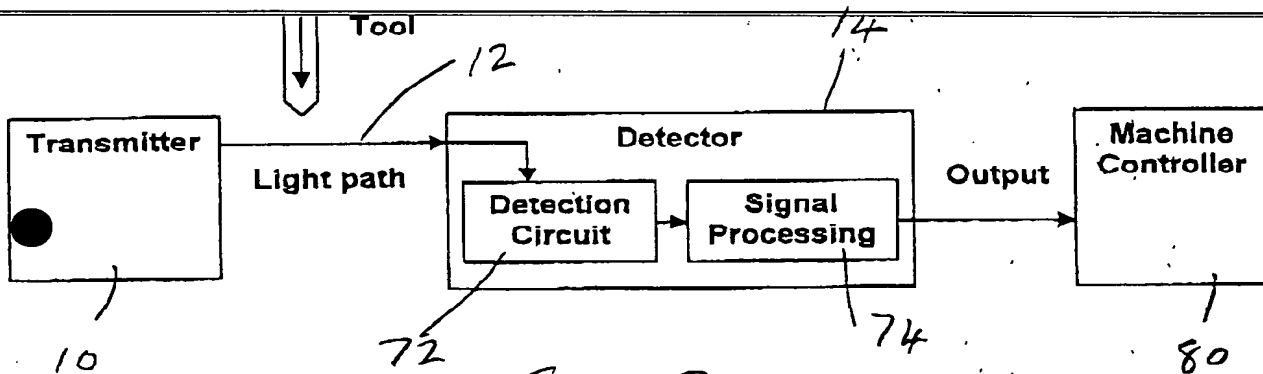


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F. 9 3

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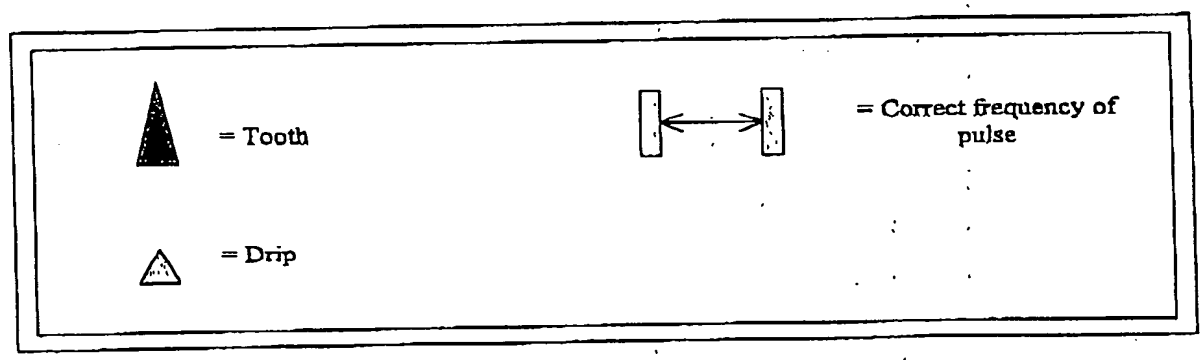
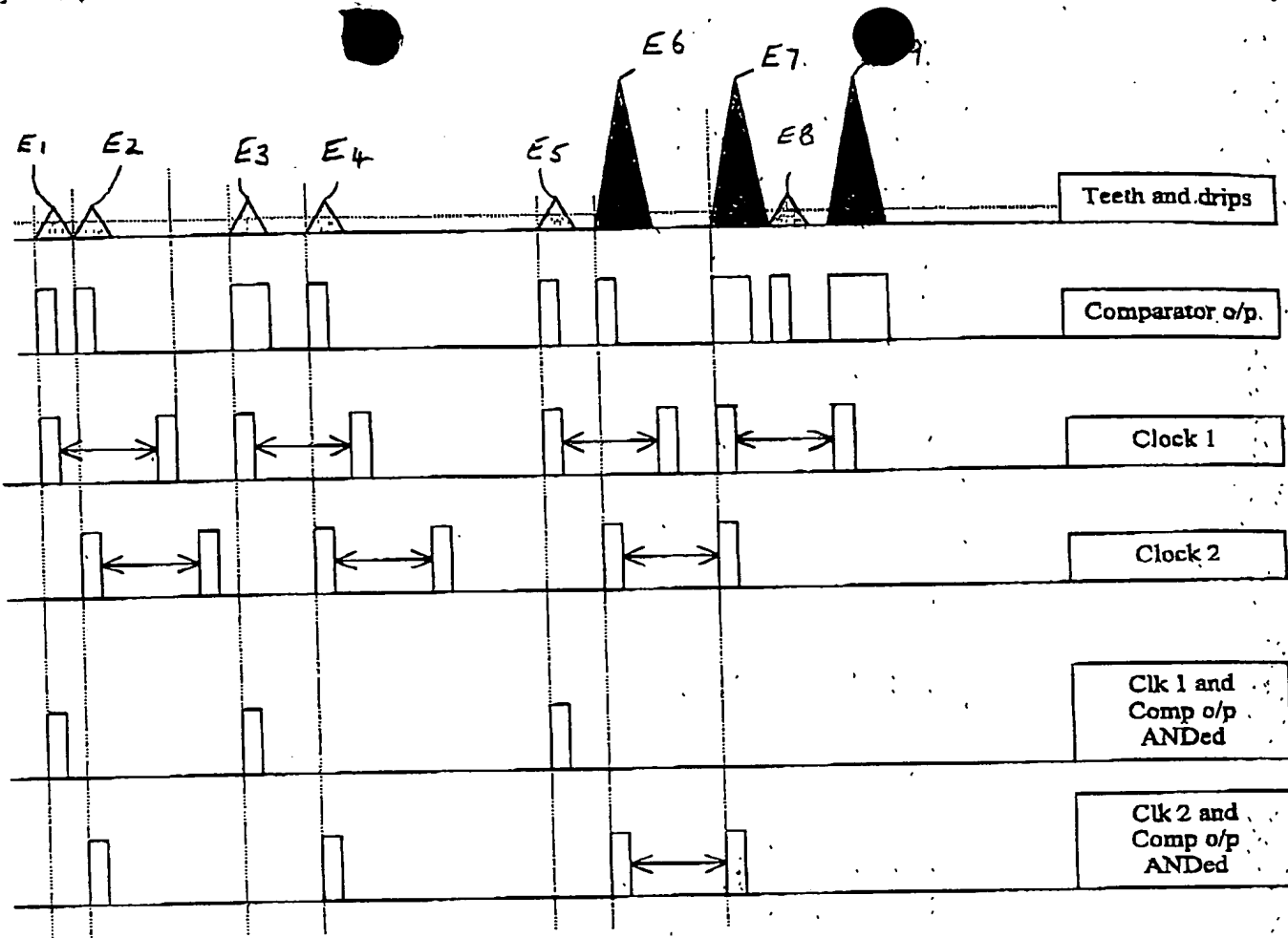


FIG 4

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